

NUTEV ANOMALY & STRANGE-ANTISTRANGE ASYMMETRY

BO-QIANG MA

Department of Physics, Peking University, Beijing 100871, China

E-mail: mabq@phy.pku.edu.cn

The NuTeV Collaboration reported a value of $\sin^2 \theta_w$ measured in neutrino-nucleon deep inelastic scattering, and found that the value is three standard deviations from the world average value of other electroweak measurements. If this result cannot be explained within conventional physics, it must imply some novel physics beyond the standard model. We report the correction from the asymmetric strange-antistrange sea by using both the light-cone baryon-meson fluctuation model and the chiral quark model, and show that a significant part of the NuTeV anomaly can be explained by the strange-antistrange asymmetry.

The NuTeV Collaboration¹ at Fermilab has measured the value of the Weinberg angle (weak mixing angle) $\sin^2 \theta_w$ in deep inelastic scattering (DIS) on nuclear target with both neutrino and antineutrino beams. Having considered and examined various source of systematic errors, the NuTeV Collaboration reported the value:

$$\sin^2 \theta_w = 0.2277 \pm 0.0013 (\text{stat}) \pm 0.0009 (\text{syst}),$$

which is three standard deviations from the value $\sin^2 \theta_w = 0.2227 \pm 0.0004$ measured in other electroweak processes. As θ_w is one of the important quantities in the standard model, this observation by NuTeV has received attention by the physics society. This deviation, or NuTeV anomaly as people called, could be an indication for new physics beyond standard model, if it cannot be understood by a reasonable effect within the standard model.

The NuTeV Collaboration measured the value of $\sin^2 \theta_w$ by using the ratio of neutrino neutral-current and charged-current cross sections on iron¹. This procedure is closely related to the Paschos-Wolfenstein (PW) relation²:

$$R^- = \frac{\sigma_{NC}^{\nu N} - \sigma_{NC}^{\bar{\nu} N}}{\sigma_{CC}^{\nu N} - \sigma_{CC}^{\bar{\nu} N}} = \frac{1}{2} - \sin^2 \theta_w, \quad (1)$$

which is based on the assumptions of charge symmetry, isoscalar target, and strange-antistrange symmetry of the nucleon sea.

There have been a number of corrections considered for the PW relation, for example: charge symmetry violation³, neutron excess⁴, nuclear effect⁵, strange-antistrange asymmetry^{6,7,8}, and also source for physics beyond standard model⁹. In this talk, I will report on the effect due to the strange-antistrange asymmetry by using both the light-cone baryon-meson fluctuation model¹⁰ and the chiral model model^{11,12}, based on the collaborated works with Ding⁷ and also with Ding and Xu⁸.

Among various sources, it is necessary to pay particular attention to the strange-antistrange asymmetry, which brings the correction to the PW relation⁷

$$R_N^- = \frac{\sigma_{NC}^{\nu N} - \sigma_{NC}^{\bar{\nu} N}}{\sigma_{CC}^{\nu N} - \sigma_{CC}^{\bar{\nu} N}} = R^- - \delta R_s^-, \quad (2)$$

where δR_s^- is the correction term

$$\delta R_s^- = (1 - \frac{7}{3} \sin^2 \theta_w) \frac{S^-}{Q_v + 3S^-}, \quad (3)$$

where $S^- \equiv \int_0^1 x[s(x) - \bar{s}(x)]dx$ and $Q_v \equiv \int_0^1 x[u_v(x) + d_v(x)]dx$. A common assumption about the strange sea is that the s and \bar{s} distributions are symmetric, but in fact this is established neither theoretically nor experimentally. It has been argued recently that there is a strange-antistrange asymmetry in perturbative QCD at three-loops¹³, although this perturbative source can only contribute trivially to the NuTeV anomaly. Pos-

sible manifestations of nonperturbative effects for the strange-antistrange asymmetry have been discussed along with some phenomenological explanations^{10,14,15,16,17,18}. Also there have been some experimental analyses^{19,20,21,22}, which suggest the s - \bar{s} asymmetry of the nucleon sea.

It is still controversial whether the strange-antistrange asymmetry can account for the NuTeV anomaly²³. Cao and Signal⁶ reexamined the strange-antistrange asymmetry using the meson cloud model¹⁴ and concluded that the second moment $S^- \equiv \int_0^1 x[s(x) - \bar{s}(x)]dx$ is fairly small and unlikely to affect the NuTeV extraction of $\sin^2 \theta_w$. Oppositely, Brodsky and I¹⁰ proposed a light-cone baryon-meson fluctuation model to describe the $s(x) - \bar{s}(x)$ distributions and found a significantly different case from what obtained by using the meson cloud model^{14,16}, as has been illustrated recently by Ding and I⁷. Also, Szczurek *et al.*²⁴ suggested that the effect of $SU(3)_f$ symmetry violation may be specially important in understanding the strangeness content of the nucleon within the effective chiral quark model, and compared their results with those of the traditional meson cloud model qualitatively.

I first present the results by Ding and I⁷ in the light-cone baryon-meson fluctuation model. In the light-cone formalism, the hadronic wave function can be expressed by a series of light-cone wave functions multiplied by the Fock states, for example, the proton wave function can be written as

$$|p\rangle = |uud\rangle \Psi_{uud/p} + |uudg\rangle \Psi_{uudg/p} + \sum_{q\bar{q}} |uudq\bar{q}\rangle \Psi_{uudq\bar{q}/p} + \dots \quad (4)$$

Brodsky and I made an approximation¹⁰, which suggests that the intrinsic sea part of the proton function can be expressed as a sum of meson-baryon Fock states. For example: $P(uuds\bar{s}) = K^+(u\bar{s}) + \Lambda(uds)$ for the intrinsic strange sea, the higher Fock states are less important, the ud in Λ serves as a spectator in the quark-spectator model²⁵, for which we

choose

$$\Psi_D(x, \mathbf{k}_\perp) = A_D \exp(-M^2/8\alpha_D^2), \quad (5)$$

$$\Psi_D(x, \mathbf{k}_\perp) = A_D(1 + M^2/\alpha_D^2)^{-P}, \quad (6)$$

where $\Psi_D(x, \mathbf{k}_\perp)$, is a two-body wave function which is a function of invariant masses for meson-baryon state:

$$M^2 = \frac{m_1^2 + \mathbf{k}_\perp^2}{x} + \frac{m_2^2 + \mathbf{k}_\perp^2}{1-x}, \quad (7)$$

where \mathbf{k}_\perp is the initial quark transversal momentum, m_1 and m_2 are the masses for quark q and spectator D , α_D sets the characteristic internal momentum scale, and P is the power constant which is chosen as $P = 3.5$ here. The momentum distribution of the intrinsic s and \bar{s} in the $K^+\Lambda$ state can be modelled from the two-level convolution formula:

$$s(x) = \int_x^1 \frac{dy}{y} f_{\Lambda/K^+\Lambda}(y) q_{s/\Lambda}(x/y),$$

$$\bar{s}(x) = \int_x^1 \frac{dy}{y} f_{K^+/K^+\Lambda}(y) q_{\bar{s}/K^+}(x/y), \quad (8)$$

where $f_{\Lambda/K^+\Lambda}(y)$, $f_{K^+/K^+\Lambda}(y)$ are the probabilities of finding Λ, K^+ in the $K^+\Lambda$ state with the light-cone momentum fraction y , and $q_{s/\Lambda}(x/y)$, $q_{\bar{s}/K^+}(x/y)$ are the probabilities of finding s, \bar{s} quarks in Λ, K^+ state with the light-cone momentum fraction x/y . Two wave function models, the Gaussian type and the power-law type, are adopted¹⁰ to evaluate the asymmetry of strange-antistrange sea, and almost identical distributions of s - \bar{s} are obtained in the nucleon sea. In this work, we also consider the two types of wave functions, Eqs. (5) and (6).

The u and d valence quark distributions in the proton are calculated by using the quark-diquark model²⁵. The unpolarized valence quark distribution in the proton is

$$u_V(x) = \frac{1}{2}a_S(x) + \frac{1}{6}a_V(x),$$

$$d_V(x) = \frac{1}{3}a_V(x), \quad (9)$$

where $a_D(x)$ ($D = S$ or V , with S standing for scalar diquark Fock state and V standing for vector diquark state) denotes that the

amplitude for the quark q is scattered while the spectator is in diquark state D , and can be written as:

$$a_D(x) \propto \int [d\mathbf{k}_\perp] \left| \Psi_D(x, \mathbf{k}_\perp) \right|^2. \quad (10)$$

The values of parameters α_D , m_q , and m_D can be adjusted by fitting the hardonic properties. For light-flavor quarks, we simple choose $m_q = 330$ MeV, $\alpha_D = 330$ MeV, $m_S = 600$ MeV, $m_V = 900$ MeV and $m_s = m_{\bar{s}} = 480$ MeV¹⁰. Because the fluctuation functions were normalized to 1 in Ref.¹⁰, we can obtain the different distributions for s and \bar{s} in the nucleon. In the same way, we can get the distributions of the u and d valence quarks, for which the integrated amplitude $\int_0^1 dx a_D(x)$ must be normalized to 3 in a spectator model^{25,26}. Assuming isospin symmetry, we can get the valence distributions in the nucleon which implies $N = (p + n)/2$

$$\begin{aligned} u_V^N(x) &= \frac{1}{2} \left[\frac{1}{2} a_S(x) + \frac{1}{2} a_V(x) \right], \\ d_V^N(x) &= \frac{1}{2} \left[\frac{1}{2} a_S(x) + \frac{1}{2} a_V(x) \right]. \end{aligned} \quad (11)$$

Thus, using this model, we obtain the distributions of s and \bar{s} in the nucleon sea. The numerical result is given in Fig. 1. One can find that $s < \bar{s}$ as $x < 0.235$, $s > \bar{s}$ as $x > 0.235$, this result is opposite to the prediction from the meson cloud model⁶. From Eq. (2), one can find that a shift of δR_s^- should lead to a shift in the R^- , which affect the extraction of $\sin^2 \theta_w$, Eq. (3). The result of our calculation is $0.0042 < S^- < 0.0106$ ($0.0035 < S^- < 0.0087$) for the Gaussian wave function (for the power-law wave function), which corresponds to $P_{K^+\Lambda}=4\%$, 10% . Hence, $0.0017 < \delta R_s^- < 0.0041$ ($0.0014 < \delta R_s^- < 0.0034$), for the Gaussian wave function (the power-law wave function). The shift in $\sin^2 \theta_w$ can reduce the discrepancy from 0.005 to 0.0033 (0.0036) ($P_{K^+\Lambda}=4\%$) or 0.0009 (0.0016) ($P_{K^+\Lambda}=10\%$).

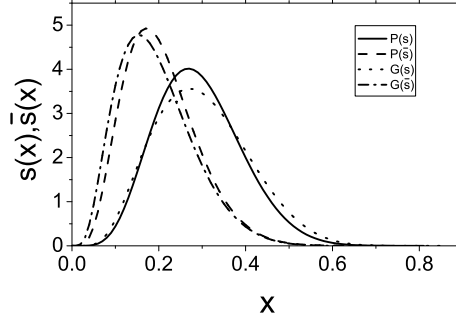


Figure 1. Distributions for $s(x)$ and $\bar{s}(x)$ in the light-cone baryon-meson fluctuation model. $P(s)$ ($G(s)$) is the s distribution with the power-law wave function (the Gaussian wave function) and $P(\bar{s})$ ($G(\bar{s})$) is the corresponding \bar{s} distribution.

In the above, our attention is on the distributions of $s(x)$ and $\bar{s}(x)$, and on calculating the second moment S^- by using the light-cone baryon-meson fluctuation model¹⁰. We find that the s - \bar{s} asymmetry can remove the NuTeV anomaly by about 30–80%.

A further study by Ding, Xu and I⁸ by using chiral quark model also shows that this strange-antistrange asymmetry has a significant contribution to the PW relation and can explain the anomaly without sensitivity to input parameters. The chiral symmetry at high energy scale and it breaking at low energy scale are the basic properties of QCD. The chiral quark model, established by Weinberg¹¹, and developed by Manohar and Georgi¹², has been widely accepted by the hadron physics society as an effective theory of QCD at low energy scale. This model has also a number of phenomenological applications, such as to explain the light-flavor sea asymmetry of u and d sea quarks²⁷, and also to understand the proton spin problem²⁸. In this new work, we provide a new success to understand the NuTeV anomaly with the chiral quark model without sensitivity on parameters. We find that the effect due to strange-antistrange asymmetry can

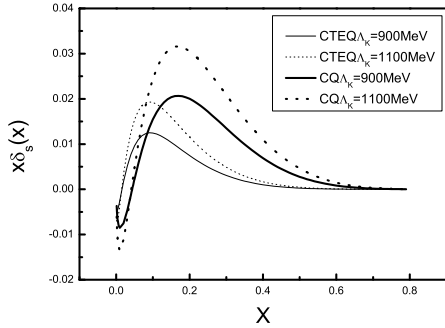


Figure 2. The distributions of $x[s(x) - \bar{s}(x)]$ in the chiral quark model, with inputs of valence quark distributions from both constituent quark (CQ) model (thick curves) and CTEQ6 parametrization (thin curves), and the cut-off parameter $\Lambda_K = 900$ MeV (solid curves) and 1100 MeV (dashed curves).

bring a significant contribution to the NuTeV anomaly of about 60–100% with reasonable parameters without sensitivity to different inputs of constituent quark distributions. This may imply that the NuTeV anomaly can be considered as a phenomenological support to the strange-antistrange asymmetry of the nucleon sea. Thus it is important to make a precision measurement of the distributions of $s(x)$ and $\bar{s}(x)$ in the nucleon more carefully in future experiments.

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